DDT Project: Background and Overview

Satoshi Tadokoro[1,2], Fumitoshi Matsuno[3,1], Hajime Asama[4,1], Masahiko Onosato[5,1], Koichi Osuka[6,1], Tomoharu Doi[7,1], Hiroaki Nakanishi[8,1], Itsuki Noda[9,1], Koichi Suzumori[10,1], Toshi Takamori[1], Takashi Tsubouchi[11,1], Yasuyoshi Yokokohji[8,1], and Mika Murata[1]

[1] International Rescue System Institute
KIMEC Bldg 2F, 1-5-2 Minatojima-Minami, Chuo-ku, Kobe 650-0047 Japan
Kawasaki Industrial Development Bldg., 66-20 Horikawa, Saiwai-ku, Kawasaki 212-0013 Japan
http://www.rescuesystem.org/
[2] Tohoku University
6-6-01 Aramaki-Aza-Aoba, Aoba-ku, Sendai 980-8579 Japan
tadokoro@rm.is.tohoku.ac.jp
http://www.rm.is.tohoku.ac.jp/
[3] The University of Electro-Communications
[4] The University of Tokyo
[5] Hokkaido University
[6] Kobe University
[7] Osaka Prefectural College of Technology
[8] Kyoto University
[9] National Institute of Advanced Industrial Science and Technology (AIST)
[10] Okayama University
[11] University of Tsukuba

Abstract. DDT Project on rescue robots and related technologies was performed in Japan's fiscal years of 2002-2006 by nationwide researchers, and was organized by International Rescue System Institute. The objective of this project is practical development of technologies related to robotics against earthquake disasters, which include robots, intelligent sensors, information equipment, and human interfaces that support emergency response such as urban search and rescue, especially victim search, information gathering and communication. Typical technologies are, for examples, teleoperated robots for victim search in hazardous disaster area, and robotic systems with distributed sensors for gathering disaster information to support human decision making. This paper introduces the background behind the DDT Project, i.e. earthquake disasters, Japan Government's policy, the objective of this project, and a brief overview of the research results.

1 Earthquake Disasters

Many Japan's ancient documents describe disasters such as earthquakes, wind storms, floods, epidemics, wars and conflicts, because large-scale disasters have repeatedly attacked and have given huge damage to this country. Hanshin-Awaji

Earthquake attacked Kobe City in 1995, which killed 6,435 people and destroyed more than 110,000 houses.

The Headquarter for Earthquake Research Promotion of Ministry of Education, Culture, Sports, Science and Technology (MEXT) has given an assessment that the probability of Nankai and Tonankai Earthquakes of magnitude 8.5 is 50-60% and that of Miyagi Offshore Earthquake of magnitude 7.5 is 99%. Table 1 shows estimated number of casualties if the Nankai EQ and Tonankai EQ simultaneously happen [1, 2]. This number means that the damage is catastrophic. We must note that this simultaneous shake is possible according to the historical facts.

Table 1. Predicted number of casualties and victims in the case of simultaneous shake of Nankai Earthquake and To-nankai Earthquake [1].

			Number of victims		
Item		Time of incidence	5 am	Noon	18 pm
Casualty	Shake		6,000	2,900	4,000
	Tsunami	Well aware of evacuation	3,300	2,200	2,300
		Poor aware of evacuation	8,600	4,100	5,000
	Slope collapse		2,100	1,100	1,300
	Fire	Wind: 3 m/s	100	60	900
		Wind: 15 m/s	500	200	2,200
	Large-scale landslide		Can be very large depending on the place		
	Total	Wind: 3 m/s	12,100-17,400	6,300-8,100	8,500-11,200
		Wind: 15 m/s	12,500-17,800	6,400-8,200	9,800-12,500
Seriously injured in total			20,400	16,100	17,300
Need rescue in total			40,400	22,400	26,900

Table 2 shows that many large-scale earthquakes in the 20th century have occurred in Asia. The world disaster statistics in 1990-1999 shown in Table 3 indicates that the earthquake damage was one of the three most serious disasters. 87% of the deaths was caused by natural disasters, and this is far more than victims of non-natural disasters [3].

Table 4 shows risk indices of cities in the world, which was estimated by Munich Re. This shows Japanese major cities, Tokyo, Yokohama, Kawasaki, Osaka, Kobe and Kyoto are exposed to high risks [4].

Disaster science and technology, especially the fields of earthquake seismology, geology, civil engineering and architectonics have contributed to minimize the damage. When we observe recent cases in Japan, earthquakes of large magnitude did not necessarily result in immense damage. This is because these technologies improved robustness of the cities against disaster.

However, the Hanshin-Awaji Earthquake raised an issue that the current level of countermeasures is not sufficient in the case of large-scale urban disasters. Further research and development are necessary not only for the conventional disaster science and technology but also for new areas including robotics.

Table 2. History of earthquake disasters in the 20th century.

Year	Country/Region	Magnitude	Number of Death
1976	China	M7.8	242,700
1920	China	M8.6	220,000
1923	Japan	M7.9	142,800
1908	Italy	M7.0	110,000
1927	China	M7.9	80,000
1970	Peru	M7.6	66,800
1935	Pakistan	M7.6	60,000
1990	Iran	M7.3	41,000
1939	Turkey	M7.8	32,700
1915	Italy	M6.9	32,600

Table 3. Total number of people reported killed and total amount of estimated damage by continent and by type of phenomenon (1990-1999) [3]. The upper number is the number of casualties and the lower number is the amount of damage in million USD.

Criteria	Africa	Americas	Asia	Europe	Oceania	Total
Avalanches/	225	2,010	5,500	644	279	8,658
landslides		515	388	24		929
Droughts	12		2,680		98	2,790
	116	4,440	2,819	9,888	3,676	21,941
Earthquakes	816	3,519	91,878	2,395	70	98,678
	282	23,810	183,782	6,893	255	215,023
Epidemics	57,082	12,123	14,316	411	115	84,047
Extreme	1,102	1,998	5,974	954	27	9,055
temperatures	47	8,251	3,968	2,096		14,363
Floods	9,487	35,598	55,916	2,839	30	103,870
	79	35,975	112,575	93,638	796	243,561
Forest/scrub	79	101	260	127	8	575
fires		3,498	32,299	1,021	156	36,975
Wind	1,612	13,264	185,739	913	262	201,790
storms	1,149	86,941	60,640	26,114	4,545	179,392
Volcanoes		77	994		9	1,080
		33	223	16	400	673
Other natural		15	489		2,182	2,686
disasters	5	104				109
Non-natural	16,136	12,353	42,453	7,832	534	79,308
disasters	362	14,661	4,381	8,496	164	28,066
Total	85,551	81,058	406,199	16,115	3,614	592,537
	2,540	178,230	401,079	148,189	10,994	741,033

Table 4. Risk indices of large cities estimated by natural hazards [4].

City	Risk index as a whole 1),2)	Hazard 3)	Susceptibility to loss 3)	Values 3)
Tokyo, Yokohama, Kawasaki	710	10.0	7.1	10.0
San Francisco, Oakland, San Jose	167	6.7	8.3	3.0
Los Angeles, Riverside, Orange County	100	2.7	8.2	4.5
Osaka, Kobe, Kyoto	92	3.6	5.0	5.0
Miami, Fort Lauderdale	45	2.7	7.7	2.2
New York, Nothern New Jersey, Long Island	42	0.9	5.5	8.3
Hong Kong	41	2.8	6.6	1.9
Manila	31	4.8	9.5	0.7
London	30	0.9	7.1	4.8
Paris	25	0.8	6.6	4.6

1) Risk = Hazard × Loss susceptibility × Values
2) Total material loss, not the insured share
3) Scaled to max. value = 10

2 Important Research Themes

Task Force on Future Countermeasures Against Earthquakes of Central Disaster Prevention Council, Japan Cabinet Office reported the following issues in earthquake disasters in 2002 [5].

1. Unsolved problems in countermeasures after Hanshin-Awaji EQ
   (a) Fragility and impracticalness of response ability of the government and local governments in unexpected disaster
   (b) Unplanned scheme of service of individuals and private companies in disaster
   (c) Unresolved scheme of efficient effective methods of improvement of earthquake reduction facilities
2. Problems caused by change of economy and social situation in Japan
   (a) Slowdown of economic growth
   (b) Decline of local community
   (c) Growing citizens' awareness of safety and security
   (d) Aging of population and falling birthrates
   (e) Accelerated technology development especially in information technology

It mentions that the following key strategies are essential to resolve the above issues.

1. On the basis of the developed systems and organizations against earthquake disaster after the Hanshin-Awaji EQ, their substantial effectiveness is enhanced by improving efficiency of operations and social awareness.
2. Disaster mitigation functions are established in ordinary social systems as far as possible, because citizens' concern about the disaster problem is gradually fading after the peak at the Hanshin-Awaji EQ.
3. Practical risk management systems, social cooperation in disaster, effective efficient countermeasures, and full use of advanced technologies move ahead.

This report advises the following actions as immediate measures.

1. Establishment of practical risk management systems
   (a) Establishment of thoroughly practical systems of disaster reduction
   Development of manuals showing concrete procedures, education of expert staffs, improvement of mobility of expert organizations, cooperation of organizations in medical services, emergency logistics, etc.
   (b) Wide-area disaster reduction systems
   Development of collaborative wide-area action plans of multiple local governments for disaster mitigation, standardization and sharing of disaster response systems, equipment, material, information, etc.
2. Social cooperation in disaster
   (a) Local collaboration of governments with private sectors
   Development of disaster mitigation plan and administrative plan utilizing local communities on the basis of local collaboration of governments with residents, companies, non-profit organizations, etc.
   (b) Cooperation with volunteer activities
   Development of systems of volunteers' participation, training of coordinators, systems of specialists' support
   (c) Disaster mitigation by private companies
   Development of cooperation systems with companies that have various functions in disaster such as supplying goods and services to the ground zero, evaluation of companies from the viewpoint of risk management for safety and security of employees and customers and of minimization of economic loss
   (d) Information sharing in disaster
   Development of information sharing systems within disaster mitigation agencies, and those between residents and the agencies
   (e) Robustness of cities against earthquakes
   Promotion of upgrade of urban infrastructure for robustness against earthquake, utilization of development tactics by which private companies and land owners feel benefit
3. Effective efficient countermeasures for disaster reduction
   (a) Weighted countermeasures considering budget limitation
   Development of upgrade indices and desirable levels of earthquake disaster mitigation facilities, guideline of objective evaluation of mitigation systems, and system for steadily performing these plans

   (b) Reinforcement of houses and public buildings of importance for disaster mitigation
       Development of hazard maps, diagnosis of seismic qualification, refurbishment for earthquake resistant, synthetic program for both software and hardware
   (c) Introduction of economic principle into disaster mitigation
       Development of performance indices of effectiveness of products in disaster, display of disaster conscious products, evaluation systems of disaster-resistive products in market
4. Full use of advanced technologies
   (a) Advanced information systems
       Development of advanced disaster mitigation information systems effective from just after disaster to recovery and reconstruction
   (b) Technologies and systems eliminating various barriers
       Development of technologies for information transfer and evacuation guidance to/for people who need assistance in disaster, robots and systems that can work in inaccessible area
   (c) Technologies and systems for overcoming fragility of the convenient society
       Development of robust infrastructure for ordinary life against disruption by failure of electric power and communication

Robotics is expected its contribution to the above wide-spectrum of actions. DDT Project is related to the above as follows.

Tightly coupled action:	4b
Closely related actions:	2d, 4a
Rather closely related action:	1b
Related actions:	1a, 3b, 3c, 4c

It is desirable to contribute many of the above actions, and the research should be done for wide range.

3 Urban Search and Rescue

Figure 1 shows number of victims rescued by Kobe Fire Department at Hanshin-Awaji EQ [6]. This data shows that immediate search and rescue are important since the survival rate gradually decreases as time passes. It is desirable to be rescued within 3 hours. The survival rate drastically decreases after 3 days. This period is called *golden 72 hours* by first responders.

Typical process of urban search and rescue (USAR) is as follows [7].

1. Awareness
   Become aware that survivors remain in a rubble pile, in many cases, by direct voice from the rubble pile or by report of their family and residents.

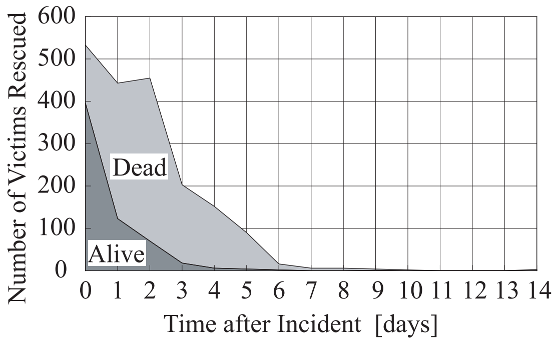

Fig. 1. Decrease of numbers of survivors and casualties who were rescued in Hanshin-Awaji Earthquake by Kobe Fire Department.

2. Situation assessment
   Assess risk of collapse of structures, existence of gases, oxygen, hazardous materials and fire.
3. Planning
   Plan the procedure and task assignment, request backup parties, equipment and material, and arrange logistics.
4. Search
   Identify positions of the survivors in detail. Topological information based on characteristic landmarks is desirable for human rescuers. Absolute coordinate cannot be used in rubble piles where axis does not exist.
5. Excavation
   Remove rubbles so that the survivor bodies can move. The survivors must not be injured. The search process frequently needs the excavation process, and these two must be performed simultaneously.
6. Secure
   Secure the survivor bodies.
7. Emergency medicine
   Medical examination, first aid and psychological assist are performed. Confined medicine is sometimes necessary, by which medical procedure is performed in rubble pile right after finding.
8. Transfer
   Transfer the survivors to medical institutions. Traffic jam and acceptability of the medical institutions usually become a problem.
9. Report
   Report the operation.

Robots and information equipment can contribute to many of the above, e.g. 2, 4, 5, 6, 7, 8, at least.

Detail of 4 and 5 are as follows according to observation of training of International Disaster Relief Team of Japan International Cooperation Agency.

1. Removal
   Remove rubbles on the approach path. Crowbars, pneumatic jacks and hydraulic jacks are used as equipment.
2. Prevention of collapse
   Prevent collapse of the approach path. Supporting lumbers and hydraulic rescue supports are used.
3. Search
   Search survivors. Search cams, fiber scopes, electro-magnetic radars and acoustic detectors are typical advanced equipment.
4. Confined medicine
   Verbal contact, examination of survivors' conditions and triage are performed. Examination of external injury, heart pulse and crush syndrome is important.
5. Safety
   Emergency evacuation and rotation of parties are necessary. Secondary disaster must be prevented. Planned rotation is essential in long-term operations.
6. Command
   Command parties, report situations, and request backup parties, equipment and materials.

Contribution of robots and systems will be focused on the following three points.

1. Support search and rescue operations that are impossible or difficult by human ability
2. Reduce risk of secondary damage
3. Improve efficiency of operations to raise survival rate

Evaluation of robots and systems is important. Various factors should be considered from the viewpoint of first responders and procurement authorities, at least the following.

1. Are the new robots and equipment are better than the existing equipment and the other solutions?
2. In what situation are they better?
3. How large and how heavy is it?
4. Is the equipment deployable in time?
5. What are their constraint conditions?
6. How robust is it in disaster situation?
7. How are the price and the running cost?
8. How long responders must make training to use it?
9. Is it enough simple?
10. What are limitations of their functions and performance?
11. Can sufficient number of equipment be prepared?

Collapsed structures where rescue operation is performed have various properties, for example, as follows.

1. Type of structures
   Wooden structure, reinforced concrete, steel skeleton, etc.
2. Degree of collapse
   Full collapse, half collapse, damaged, or safe
3. Space
   Usable space around the collapsed structure, width of access road
4. Barriers
   Hazardous materials, gas leakage, water
5. Light
   Daytime or night
6. Sound
   Silent or heavy noise, for example by helicopters
7. Weather Season, temperature, rain,snow, wind, etc.
8. Energy source
   Electric power source, hydraulic source, pneumatic source, etc.
9. Time of operation
   Risk of collapse, fire nearby
10. Number of rescuers
    Professionals and volunteers

The access path for entering collapsed structure has a variety as follows.

1. Size of clearance
   Compressed crush with clearance of 0 - 30 cm, sparse crush with clearance of 30 - 100 cm, damaged structure with large clearance. Various clearances are observed in one house.
2. Characteristics in clearance
   Slope angle, step height, gap width, necessary turning radius, etc.
3. Obstacles in clearance
   Shape, overlap, weight, force for removal, iron nails, etc.
4. Characteristics of floor surface
   Dirt, sand, dust, cloth, strings, net, glass, water, oil, etc.

They have major effect on what type of robotic systems are effective [8].

4 Objective of DDT Project

On the basis of the above-mentioned background, DDT Project started as follows[9].

Project Manager:	Satoshi Tadokoro, Tohoku University
Managing Institute:	International Rescue System Institute
Period:	August 1st, 2002 - March 31st, 2007
Budget:	Approximately 400 M JYE a year
Number of researchers:	more than 100

The following mission statement was defined so that robots and related technologies will give solutions to the above-mentioned problems.

> DDT Project will research and develop robots, intelligent sensors, information equipment, human interfaces, etc. to support victim search, information gathering and communications for emergency response in large-scale urban earthquake disasters such as urban search and rescue. These systems and component technologies shall be useful for human disaster response activities and decision making by active intelligent information gathering and network-based information transfer and integration.

The roadmap of DDT Project is shown in Fig. 2. In the first 2-3 years, it concentrated on trial of technologies that had not been well applied to the disaster problem so as to enhance the range of applicable technologies. In the last 2-3 years, technologies with high possibility were intensively researched for brush-up, and integrated systems were developed to show the functions.

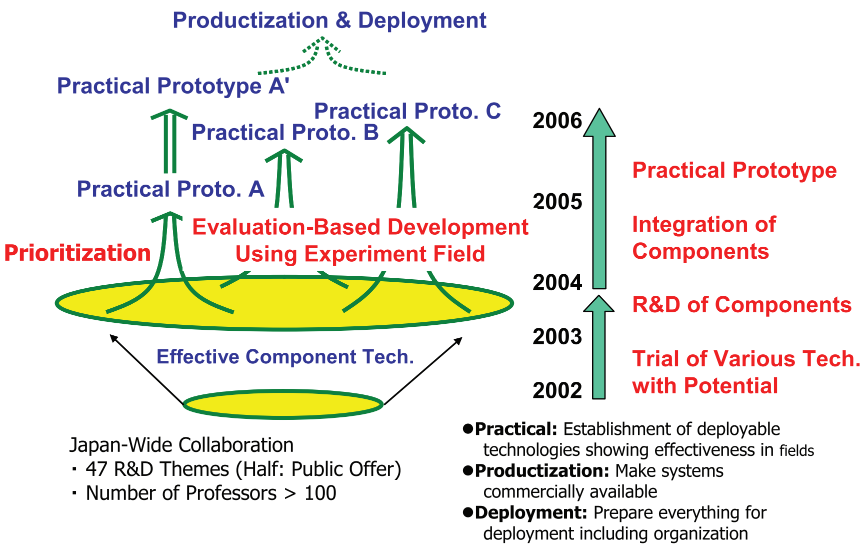

Fig. 2. Roadmap of DDT Project.

IRS established two laboratories in Kawasaki and Kobe for this project as shown in Fig. 3 and Fig. 4. They have test fields for developed systems that simulates disaster situations. Collapsed House Simulation Facility in Kobe Laboratory shown in Fig. 5 is a collapsed wooden house which was observed in Kobe. Their function is repetitive experiments and development for improvement, in addition to demonstration of developed systems and technologies in realistic situations at every stage of the project. In other words, the laboratories and facilities were used not only for academic/technical results but also for practical deployment in the future.

Fig. 3. Kawasaki Laboratory of International Rescue System Institute (IRS).

Fig. 4. Kobe Laboratory of International Rescue System Institute (IRS).

DDT Project intensively performed on-site experiments and demonstrations. Experiments at Niigata-Chuetsu EQ, training site of TFD Hyper Rescue, training sites of FEMA TFs, Collapsed House Simulation Facility, Kawasaki Laboratory and Kobe Laboratory have produced wide spectrum of lessons and knowledge for the researchers and first responders. Demonstrations at World Conference on Disaster Reduction, training of International Disaster Relief Team of Japan International Cooperation Agency, National Rescue Meet, Search and Rescue Workshop, disaster drills, expositions and exhibitions have helped rescue robots to be acknowledged by first responders and general public.

Fig. 5. Collapsed House Simulation Facility of IRS Kobe Laboratory.

This research aimed at creating various practical technologies to establish fundamentals of disaster mitigation assisted by robots at the end of this project. The definition of the word *practical* in this project is to realize technologies applicable in disaster so that experiments at real or realistic field demonstrate effectiveness of robots and systems developed. The following activities are necessary in order for these technologies to be used in real disaster.

Commercialization:	First responders can purchase the solution.
Deployment:	First responders and responding organizations can use the solution anytime.
Training:	First responders can use the solutions effectively and smoothly.
Actual Results:	First responders have used the solutions and believe its good performance.

Most research members of DDT Project are from universities. Market of developed robots and systems are not established at present, and private companies hesitate about commercialization. Procurement and deployment are dependent on governments' policies, but first responders' opinions and evaluation are important. Under this situation, DDT Project is too short to complete the above four activities, although it has made huge effort for these items as a part of research and development. Further effort must be continued by company-government-academia-private collaboration.

5 Four Mission Units (MUs)

DDT Project has consisted of the following four mission units as research groups in 2005-2006.

1. Aerial Robot System Mission Unit (ARS)
   Intelligent helicopters, balloons, image processing, human interface

2. Information Infrastructure System Mission Unit (IIS)
   Distributed sensors, RFID tags, integration protocol, database, mapping
3. In-Rubbles Robot System Mission Unit (IRS)
   Serpentine robots, advanced rescue tools, advanced search cams, advanced fiber scopes, sensors, human interface
4. On-Rubbles Robot System Mission Unit (ORS)
   Tracked vehicles, jumping robot, ultra-wide-band radar, semi-autonomous movement, ad-hoc communications, self localization and mapping, human interface, sensor data processing

At the beginning of the project, 47 research themes by 31 groups run to try various technologies according to the roadmap. In 2004, the themes were merged or abolished into 9 tasks consisting of 6 TFs forces defined by types of robots (Aerial Robot System TF, Information Infrastructure TF, In-Rubbles Robot System TF, Advanced Tool TF, On-Rubbles Robot System TF, Underground Robot System TF) and 3 TFs defined by common technologies (Control Human Interface TF, Communication and Data Format TF, Field and Evaluation TF) so that system integration is accelerated. In 2005, the TFs were integrated into the above four MUs to promote further collaborations of research members.

Figure 6 outlines a scenario by which research results are ideally applied to real earthquake disaster in the future as follows.

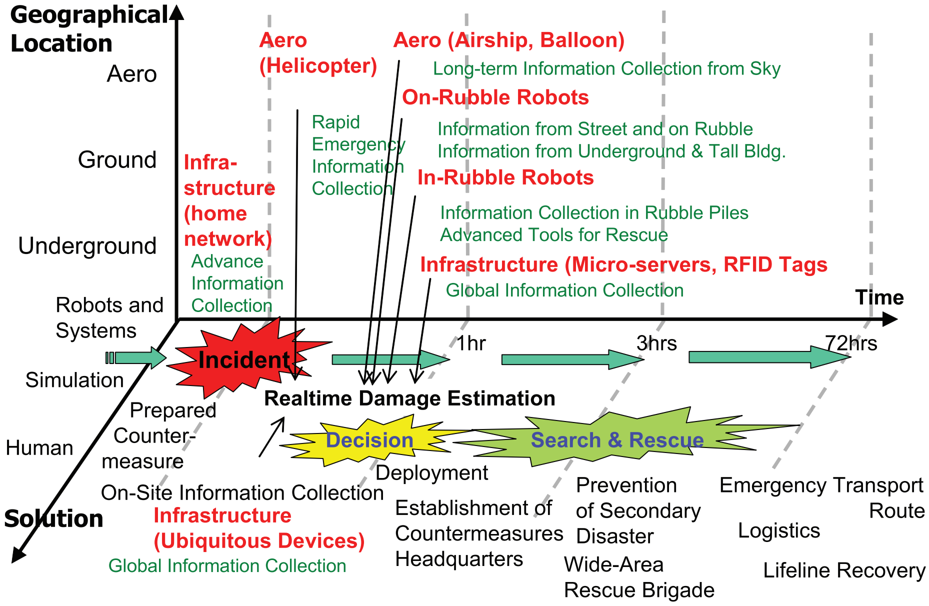

Fig. 6. Scenario by which research results are used in diaster.

-2. All the systems have been deployed and used in regular training. Common Geographic Information System (GIS) has been ready in addition to the robotic systems.
-1. Systems of IIS are continuously monitoring the situation in houses.
0. Large-scale urban earthquake disaster occurs.
1. Information of residents which has been gathered by distributed sensors, Rescue Communicators of IIS is transferred to disaster response organizations immediately after receiving Earthquake Early Warning (EEW) [12] before the shake.
2. Intelligent helicopters, Aero Robots of ARS automatically fly to gather overview information of affected area by cameras and laser profilers rapidly within 30 minutes.
3. Human first responders make decision on the basis of gathered information. Human responders are put in action carrying the developed systems.
4. InfoBalloons of ARS fly and stop in the air or move slowly. They gather victim information using infrared cameras in cooperation with Rescue Communicators of IIS and mobile phones. They collect overview information by cameras and laser profilers. They support human responders and the other robotic systems by position identification and communication transfer.
5. Robots of ORS are brought by first responders to the disaster site. They move 50 m deep on/in rubble piles to collect victim information and to investigate structural damage and hazardous materials by camera, infrared camera, temperature sensors, gas sensors, and so on, and give them to the first responders. They enter 200 m deep into underground structures and buildings of which damage is limited.
6. Robots and advanced tools of IRS are carried by the first responders to the side or the top of rubble piles. They enter 30 m deep into the rubble piles from narrow clearances by teleoperation to gather information by the sensors.
7. All the gathered information is recorded and mapped on a GIS, DaRuMa, using a standardized protocol, Mitigation Information Sharing Protocol (MISP) so that the first responders and disaster managers can use it for decision making and operation support.

6 Brief Overview of Major Results

Major results are briefly introduced in this section. The details are explained in the other papers and references.

The results are classified according to their usage as follows.

[12] EEW system by Japan Meteorological Agency (JMA) provides advance announcement of the estimated seismic intensities and expected arrival time of principal motion using difference of speed of the primary wave and the secondary wave of earthquake.

1. Equipment and systems for first responders
   Serpentine robots (Soryu, MOIRA, KOHGA, etc.), tracked vehicles (HELIOS, ACROS, Hibiscus, Ali-baba, etc.), jumping robot, advanced rescue tools (Jack-up Robot, Baribari, etc.), advanced search cam (Kurukuru, Multi Sensor Head, etc.), advanced fiber scope (Active Scope Camera, etc.), ultra-wide-band radar, wireless triage tags, etc.
2. Technologies for equipment and systems
   Sensor information processing methods, image processing methods, semi-autonomous motion algorithms, human interface, etc.
3. Equipment and systems for disaster response organizations
   Intelligent helicopters (Aero Robot, etc.), balloons (Infoballoon, etc.), database (DaRuMa), protocol (MISP), etc.
4. Infrastructure for houses
   Distributed sensors (Rescue Communicator), etc.
5. Information support for refugees
   RF-ID tags

6.1 Aerial Robot System MU

MU leader: Masahiko Onosato, Hokkaido University
MU sub-leader: Hiroaki Nakanishi, Kyoto University

Intelligent helicopter, Aero Robot Small-size autonomous unmanned helicopter shown in Fig. 7 takes off immediately after the shake to gather information at lower altitude with lower noise than manned helicopters. Technologies for stable flight in strong wind and easy teleoperation were developed.

Fig. 7. Experiments of Aero Robot and InfoBalloon in Yamakoshi Town, which Niigata-Chuetsu Earthquake attacked in 2005.

Balloon for stationary measurement, InfoBalloon InfoBalloon shown in Fig. 7 flies in sky for a long period for stationary measurement and information support of ground operation. Robustness against wind is an advantage of this research.

6.2 Information Infrastructure MU

MU leader: Hajime Asama, The University of Tokyo
MU sub-leader: Itsuki Noda, AIST

Distributed sensor, Rescue Communicator Rescue Communicators shown in Fig. 8 are installed in houses as distributed sensor equipment, and gather survivors' information by verbal contact. The information is transferred to disaster mitigation organizations by home network and ad-hoc network.

Fig. 8. Rescue Communicator and wireless triage tag (upper right).

RFID tag for triage tag and rescue completion tag The wireless triage tag shown in Fig. 8 contributes efficient logistics for rescued survivors using RFID tag. The rescue completion tag is hanged on the rescue site with storing search and rescue information. This helps to avoid repetitive operation and to improve efficiency.

6.3 In-Rubbles Robot System MU

MU leader: Koichi Osuka, Kobe University
MU sub-leader: Koichi Suzumori, Okayama University
Tomoharu Doi, Osaka Prefectural College of Technology
Yasuyoshi Yokokohji, Kyoto University

Serpentine robots, IRS Soryu, MOIRA, KOHGA, etc. Various-types of serpentine mobile mechanisms were researched and tested. The objective of these developments is search in narrow clearances wider than 30 cm in collapsed structures. They have been intensively tested in rubble piles.

Hyper Soryu IV Wide range of component technologies, which include a cable-type positioning system FST, a multi camera system, a virtual bird-eye view system using past image, a ring laser range finder, and a driving mechanism for pivot turn, were integrated into a new serpentine robot Hyper Soryu IV as shown in Fig. 9. Mobility, teleoperability, position identification and situation awareness were improved from its previous version, IRS Soryu.

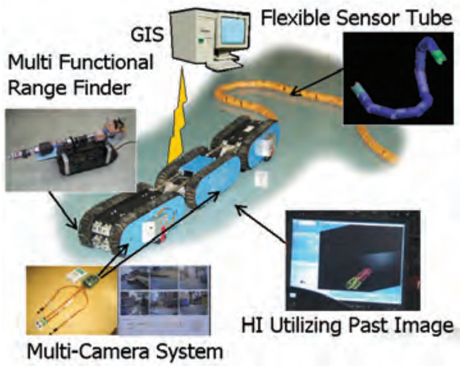

Fig. 9. Hyper Soryu IV by integration of component technologies.

Advanced rescue tools In order to improve firefighter's equipment, Multi Sensor Head that measures shape of void in rubble piles, a search cam Kurukuru that moves by hand electric generator, Jack-Up Robot for inside of rubble piles, another jack-up robot Baribari for prying narrow clearance up, Pneuma Jack, Cutter Robot, etc. were developed.

Advanced fiber scope, Active Scope Camera By adding actuators on the surface of cable of rescue video scope, Active Scope Camera shown in Fig. 10 moves by itself into clearance more than 3 cm wide. The accessible distance was drastically improved.

6.4 On-Rubbles Robot System MU

MU leader: Fumitoshi Matsuno, The University of Electro-Communications
MU sub-leader: Takashi Tsubouchi, University of Tsukuba

Mobile vehicles for rough terrain, HELIOS VIII, HELIOS Carrier, ACROS, FUMA, Hibiscus, Ali-Baba, etc. HELIOS VIII is an information gathering tracked UGV for damaged buildings with large space, and has high environment resistance. HELIOS Carrier shown in Fig. 11 was developed

Fig. 10. Experiments of Active Scope Camera at Collapsed House Simulation Facility of IRS Kobe Laboratory.

by connecting two track bodies to improve mobility at steps, and by integrating component technologies, which include a virtual bird-eye view system for teleoperation human interface using past image shown in Fig. 12, an image vibration reduction system for improving virtual reality sick, autonomous 3D map generation, and a teleoperation interface using the 3D image. Various types of UGVs such as ACROS, FUMA, Hibiscus, Ali-Baba were developed.

Fig. 11. HELIOS Carrier climbing up steps.

Jumping Robot A jumping robot with super mobility on rubble pile can move for a long period by new type of pneumatic power source utilizing triple point of carbon dioxide by which dry ice can supply enough volume of air at constant pneumatic pressure.

Ultra-Wide-Band Radar An ultra-wide-band radar sensor and signal processing technology improved performance of detection of human motion of breath in rubble piles.

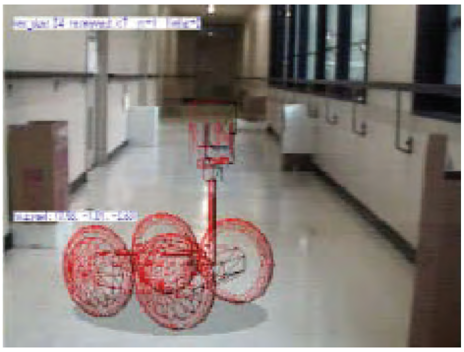

Fig. 12. Virtual bird-eye view system utilizing past image for teleoperation to enable easy navigation.

Human interface A guideline of human interface was developed aiming at future standardization.

6.5 Integration of Gathered Information

All the gathered data are integrated into distributed database DaRuMa via XML-type standardized protocol MISP (Mitigation Information Sharing Protocol), and can be referred and searched by SQL commands and viewers such as Google Earth as shown in Fig. 13. The information in the database can be attributed, added and processed afterwards via internet. It will improve efficiency of decision making. Verification experiments in Yamakoshi Town and Collapsed House Simulation Facility demonstrated its integration capability of data sent from various robots.

6.6 Verification Experiments and Exercise

A number of field experiments, demonstration and exercise were performed so that the developed systems and technologies are put into practical deployment in the future. Firefighters in active service organized a volunteer unit IRS-U, and made intensive testing and demonstrations to evaluate research results as shown in Fig. 14. First responders in FEMA evaluated the robots at their training sites in meetings of standardization of rescue robot evaluation organized by NIST and ASTM as shown in Fig. 15. General public has recognized rescue robotics research by many exhibition, demonstration and mass media.

7 Conclusions

This paper introduced background and a brief overview of research results of DDT Project.

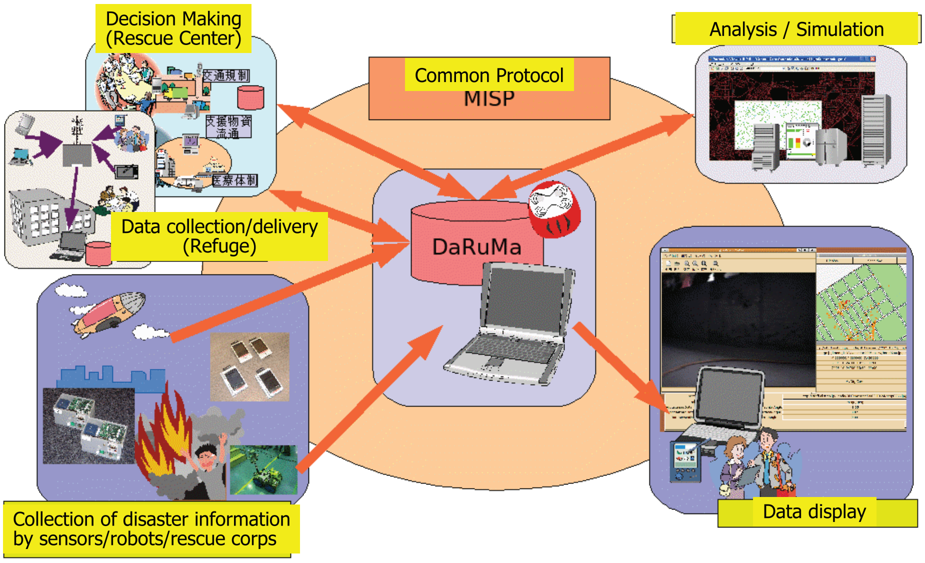

Fig. 13. Integration of gathered data from robots and systems using Mitigation Information Sharing Protocol (MISP) into DaRuMa database.

Fig. 14. Volunteer unit IRS-U organized by firefighters in active service.

Fig. 15. Experiments by FEMA first responders at Texas TF-1 training site, Disaster City of Texas A&M University.

DDT Project has established a research field of rescue robotics in Japan by defining that disaster mitigation problem is an important application area for robotics. Various systems and technologies were developed and tested in real/realistic fields by four mission units (MUs): Aerial Robot System MU, Information Infrastructure System MU, In-Rubbles Robot System MU, and On-Rubbles Robot System MU.

Communication of robotics researchers with first responders and disaster scientists has become smoother through intensive experiments, demonstrations and exercises.

Research and development of rescue robots and systems should continue to realize actual contribution to the disaster reduction, as we dreamed it in our childhood by watching TV cartoon movies. We hope this DDT Project has formed a fundamental for this technological trend.

The authors deeply thank all the people concerned and sincerely appreciate their contributions.

References

1. Web page of Central Disaster Prevention Council, Cabinet Office, Government of Japan, http://www.bousai.go.jp/ (in Japanese)
2. Material of the 8th Meeting of TF on Tonankai-Nankai Earthquake. Central Disaster Prevention Council, Cabinet Office, Government of Japan (2003) (in Japanese)
3. World Disasters Report, International Federation of Red Cross and Red Crescent Societies (2000)
4. Stephen Voss: A risk index for megacities. Munchener Ruck, Munich Re Group (2006)
5. Report of TF on Future Countermeasures against Earthquakes. Central Disaster Prevention Council, Cabinet Office, Government of Japan (2002) (in Japanese)
6. Information packet of lessons in Hanshin-Awaji Earthquake. Japan Cabinet Office, Hyogo Earthquake Memorial 21st Century Research Institute, http://www.iijnet.or.jp/kyoukun/eng/ (2000)

7. Fire Supression Division, Tokyo Fire Department: New Firefighting Strategies. Tokyo Horei Publishing Co. (2002) (in Japanese)
8. Tadokoro, S., Takamori, T., Tsurutani, S., Osuka, K.: On robotic rescue facilities for disastrous earthquakes – from the Great Hanshin-Awaji (Kobe) Earthquake –. J. Robotics and Mechatronics, **9-1** (1997) 46-56
9. Reports of Special Project for Earthquake Disaster Mitigation in Urban Areas, III-4 Development of Advanced Robots and Information Systems for Disaster Response. MEXT, NIED, IRS, (2002-2006) (in Japanese)